MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2022/2023 (TERM ID 2220)

EMF4076 – ELECTROMAGNETIC INTERFERENCE

(EC01)

7 JULY 2023
9.00 AM – 11.00 AM
(2.0 Hours)

INSTRUCTIONS TO STUDENT

1. This Question paper consists of 9 pages including cover page with 4 Questions only.
2. Attempt all questions. The distribution of the marks for each question is given.
3. Please print all your answers in the answer Booklet provided.

Question 1

(a) Figure Q1A shows the cross-section view of a three-conductors cable labeled conductor 1, 2 and GND (Ground). The conductors are protected by PVC (Polyvinyl chloride) dielectric, with relative permittivity and permeability given by $\varepsilon_r = 3.2$, $\mu_r = 1.0$. The length of the cable is 15 cm.

(i) Determine the inductance, L_{11}, L_{22}, L_{12}, and capacitance C_{1G}, C_{2G}, C_{12} for the cable and sketch the equivalent electrical circuit, the length of the cable is 16 cm. *Hint: For C_{12} calculation you can ignore the effect of GND plane.*

(ii) Determine the maximum frequency where the equivalent circuit in part (i) becomes invalid. State all assumptions.

(iii) During an experimental setup using the cable, with sinusoidal voltage at frequency 10 MHz being applied to conductor 1 and GND, a coupled voltage magnitude of 23.6 dBμV is measured across conductor 2 and GND. Determine the magnitude of the coupled voltage in volts (V).

[13 + 5 + 3 marks]

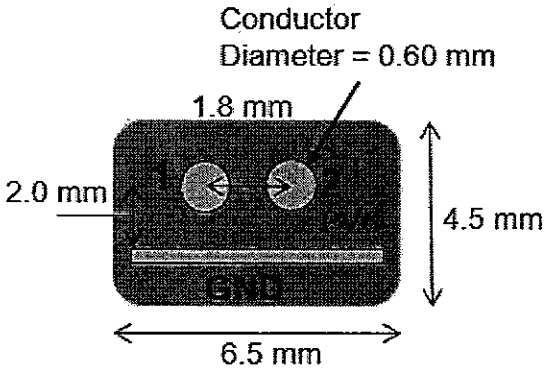

Figure Q1A.

(b) Figure Q1B shows a 4-core shielded cable (also called screened cable in the industry). Briefly explain the purpose of the shield conductor, and state how it should be connected to the system where it is being used.

[4 marks]

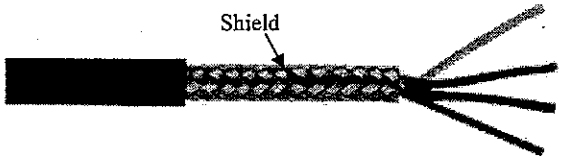

Figure Q1B.

Continued...

Question 2

(a) Figure Q2A shows a 4-layer PCB (printed circuit board) designed by the lecturer, with the top and bottom view of the assembled PCB also shown on the right. Internal copper layer 'Inner 1' is designated as GND (Ground) plane, while the rest of the 3 copper layers are used for routing signal and power connections between components.

(i) Briefly explain the purpose of having GND conductor in electronics/electrical systems.

(ii) Justify the use of GND plane (Inner 1), why not just use a conducting trace as GND, why the need to use a whole conducting plane?

(iii) Another feature of the PCB in Figure Q2A is the flooded GND on the top and bottom side, whereby every available empty space on the surface of the PCB is filled with conductor, which is then connected to the internal GND plane via plated through holes. Explain the rational of doing this in terms of reducing interference and unwanted electromagnetic emission.

[4 + 4 +4 marks]

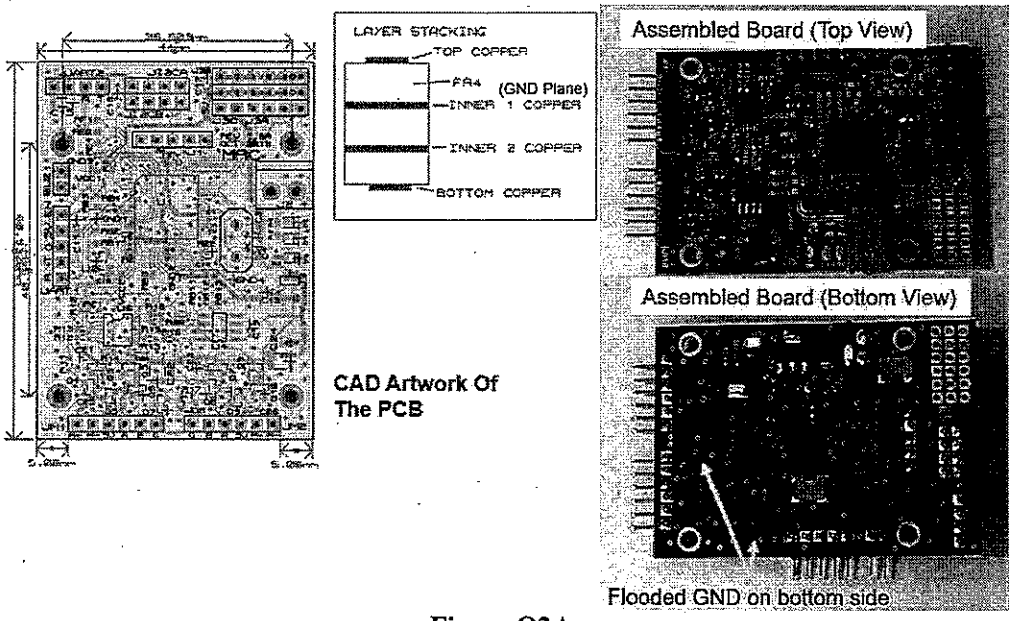

Figure Q2A.

Continued...

(b) Figure Q2B is the simplified view of a multi-layer PCB (printed circuit board) with the dielectric layer not shown. The buffer is transmitting a series of digital voltage pulses to another component via the internal signal trace, which is sandwiched between two conducting planes (V_{CC} and GND planes).

(i) Briefly explain the purpose of having decoupling capacitor. Use suitable diagram if necessary. Also describe the possible effects to the digital voltage pulses should the decoupling capacitor be removed.

(ii) In choosing suitable decoupling capacitor, apart from the capacitance, state two (2) physical characteristics that are desirable for optimum operation.

(iii) Figure Q2C shows two 1μF, 50V rating capacitors side-by-side. Which would be more suitable to be used as decoupling capacitor? Justify your answer.

[6 + 4 + 3 marks]

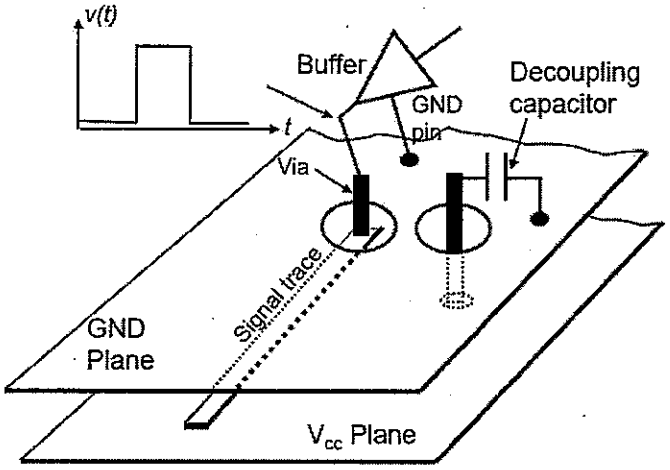

Figure Q2B.

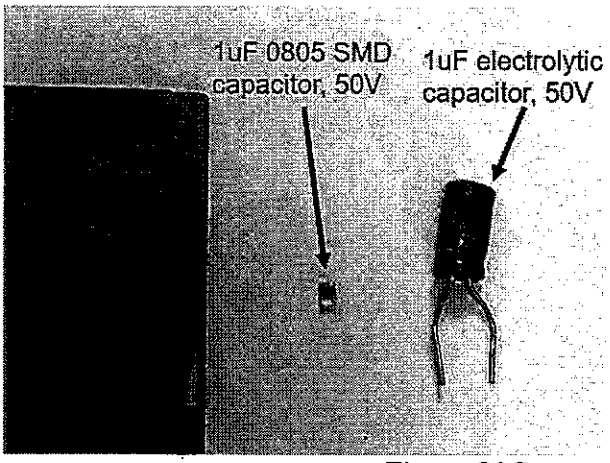

Figure Q2C.

Continued...

Question 3

(a) Figure Q3A shows an integrated circuit, IC_1 driving a 220Ω surface-mounted resistor on a printed circuit board via two copper traces. The electric current flowing in the copper trace is sinusoidal, with magnitude of 25 mA, and a frequency of 200 MHz.

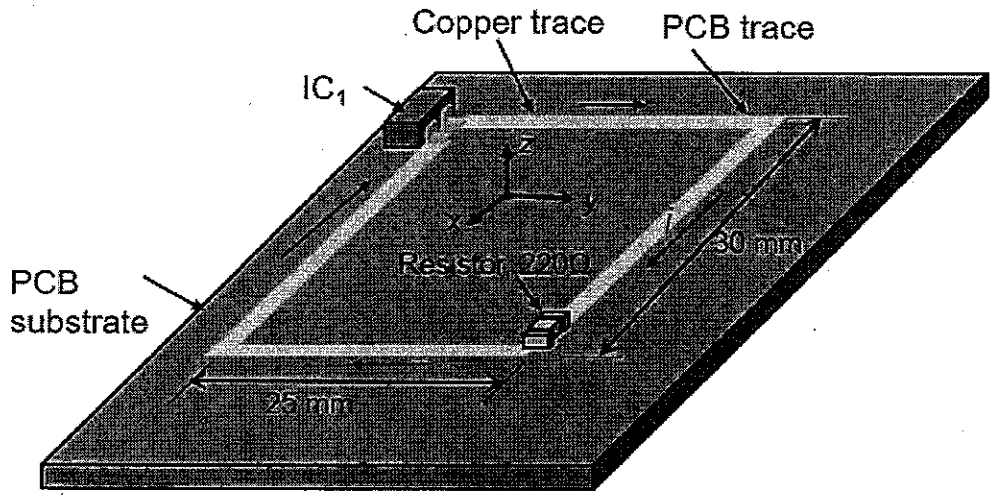

Figure Q3A.

(i) Estimate the magnitude of the electric field in μV/m and the magnitude of the magnetic field in μA/m, at a distance of 3 meters along the y-axis (see figure). Justify the equation you use (i.e., if you use near-field or far-field form for the radiation equation, you need to justify them) and show your calculation details. You can assume the free-space phase velocity and wave impedance to be 3.0×10^8 m/s and 377 Ω respectively.

(ii) If a receiving antenna is placed at 3 meters along the y-axis from the circuit board and connected to a spectrum analyzer (SA) through a coaxial cable, calculate the voltage magnitude that will be measured by the SA if the antenna has an antenna factor of 13 dBm^{-1} and the cable has loss of 0.3 dB at 200 MHz.

[13 + 6 marks]

(b) The relative permeability for copper and stainless steel is 1 and 200, respectively, while their conductivity is 5.8×10^7 S/m and 1.2×10^6 S/m, respectively. If both materials have the same thickness, justify which material is able to provide a higher absorption loss.

[6 marks]

Continued...

Question 4

(a) In your own words, explain why consideration of EMI (electromagnetic interference) is becoming more and more important beginning from the late 1980s. State at least two (2) reasons to support your argument.

[6 marks]

(b) An engineer developing an NFC (near-field communication) card reader discovered that the prototype generates excessive far-field electromagnetic radiation between 160-500 MHz. This radiation causes the device to fail the EMC (electromagnetic compatibility) test. The NFC card reader contains a micro-controller operating at 3.3V DC, with clock frequency of 160 MHz, and is powered from the mains 230V AC supply via a local AC-to-DC voltage downconverter. A few suggestions are proposed to reduce the spurious electromagnetic radiation. Indicate whether the statements below are TRUE or FALSE.

(i) If the micro-controller can function at lower clock frequency, say 80 MHz, retune the circuit to work at this frequency.
(ii) Use higher wattage resistors in the circuit board.
(iii) Stick flexible ferrite sheet to the internal wall of the enclosure.
(iv) Increase the voltage rating of the capacitors in the AC-to-DC voltage downconverter, say from 16V DC to 50V DC.

[6 marks]

(c) Figure Q4A shows the setup for measuring radiated EMI susceptibility of an equipment-under-test (EUT).

(i) Explain the purpose of having the absorbers in the shielded chamber. What would happen if the absorbers are absent?
(ii) Explain the rational of having a distance of 3 meters between the wideband antenna and the EUT, support your answer with suitable calculations.

[5 + 8 marks]

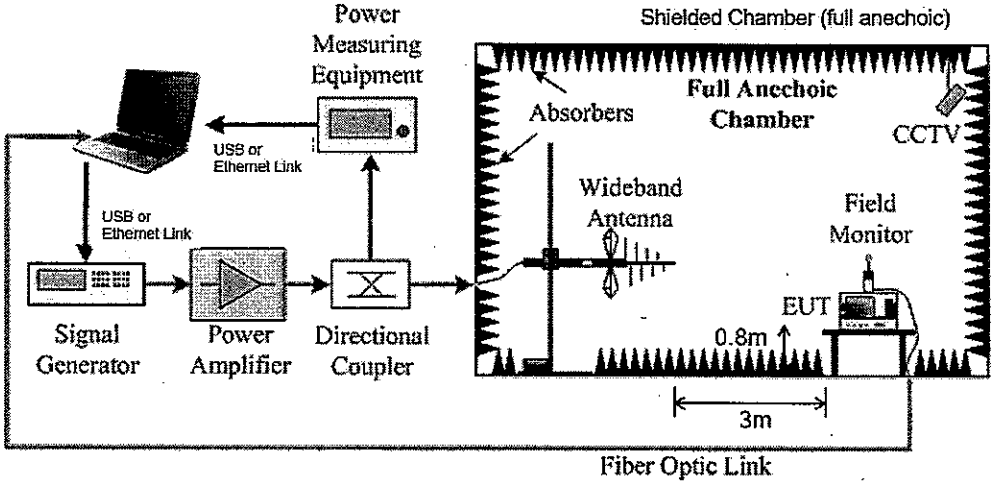

Figure Q4A.

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Useful Formula

Maxwell's Equations (in time-domain)

$$\nabla \times \boldsymbol{E} = -\frac{\partial}{\partial t}\boldsymbol{B}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial}{\partial t}\boldsymbol{D}$$

$$\nabla \cdot \boldsymbol{D} = \rho_v$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\boldsymbol{B} = \mu \boldsymbol{H} \qquad \boldsymbol{D} = \varepsilon \boldsymbol{E}$$

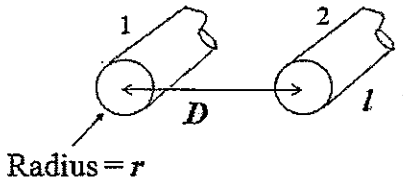
$$\mu = \mu_o \mu_r \qquad \varepsilon = \varepsilon_o \varepsilon_r$$

$\varepsilon_o = 8.85412 \times 10^{-12}$ and $\mu_o = 4\pi \times 10^{-7}$

Estimation of digital signal bandwidth

$$BW = \frac{1}{\pi\tau}$$

Inductance and capacitance for parallel conductors

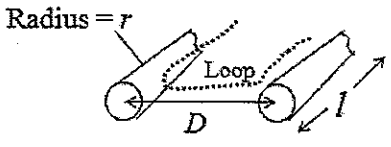


Assume D >> r

$$C \cong \frac{\pi\varepsilon l}{\ln\left(\frac{D-r}{r}\right)}$$

If radius of conductor 1 & 2 are different:

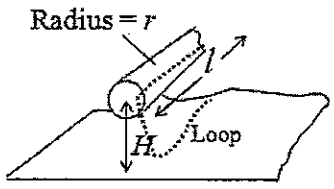
$$C \cong \frac{2\pi\varepsilon l}{\ln\left(\frac{(D-r_1)(D-r_2)}{r_1 r_2}\right)}$$



Assume $D >> r$

$$L \cong \frac{\mu l}{4\pi} + \frac{\mu l}{\pi}\ln\left(\frac{D-r}{r}\right)$$

Internal inductance



Assume $H >> r$

$$L \cong \frac{\mu l}{8\pi} + \frac{\mu l}{2\pi}\ln\left(\frac{2H-r}{r}\right)$$

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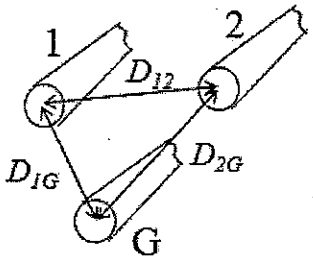
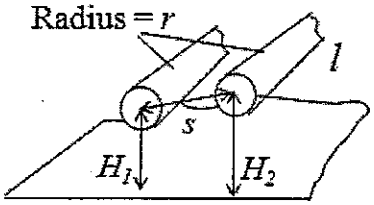


$$M_{12} \cong \frac{\mu l}{2\pi} \ln\left(\frac{D_{1G}D_{2G}}{rD_{12}}\right)$$

All conductor radius = r



$$M_{12} \cong \frac{\mu l}{4\pi} \ln\left(1+4\frac{H_1H_2}{s^2}\right)$$

Radiation

Short dipole:

- EM fields at near-field region ($kr < 0.1$):

$$\tilde{E} = \eta \frac{I_o(dl)}{4\pi}\left[2\left(\frac{1}{jkr^3}\right)\cos\theta\ \hat{a}_r + \left(\frac{1}{jkr^3}\right)\sin\theta\ \hat{a}_\theta\right]e^{-jkr}$$

$$\tilde{H} = \frac{I_o(dl)}{4\pi}\left[\left(\frac{1}{r^2}\right)\sin\theta\ \hat{a}_\varphi\right]e^{-jkr}$$

- EM fields at far-field region ($kr > 10$):

$$\tilde{E} = \eta \frac{I_o(dl)}{4\pi}\left[\left(\frac{jk}{r}\right)\sin\theta\ \hat{a}_\theta\right]e^{-jkr}$$

$$\tilde{H} = \frac{I_o(dl)}{4\pi}\left[\left(\frac{jk}{r}\right)\sin\theta\ \hat{a}_\varphi\right]e^{-jkr}$$

Continued…

Small current loop:

- EM fields at near-field region ($kr < 0.1$):

$$\tilde{E} = -\eta \frac{jkI_o A}{4\pi}\left[\left(\frac{1}{r^2}\right)\sin\theta \cdot \hat{a}_\varphi\right] e^{-jkr}$$

$$\tilde{H} = \frac{jkI_o A}{4\pi}\left[2\left(\frac{1}{jkr^2}\right)\cos\theta \;\; \hat{a}_r + \left(\frac{1}{jkr^3}\right)\sin\theta \;\; \hat{a}_\theta\right] e^{-jkr}$$

- EM fields at far-field region ($kr > 10$):

$$\tilde{E} = -\eta \frac{jkI_o A}{4\pi}\left[\left(\frac{jk}{r}\right)\sin\theta \;\; \hat{a}_\varphi\right] e^{-jkr}$$

$$\tilde{H} = \frac{jkI_o A}{4\pi}\left[\left(\frac{jk}{r}\right)\sin\theta \;\; \hat{a}_\theta\right] e^{-jkr}$$

Antenna Factor:

$$AF = \frac{\text{Incident Electric Field (V/m)}}{\text{Received Voltage (V)}} \text{ m}^{-1}$$

Or

$$AF_{dB} = \text{Incident Electric Field } (dB\mu V/m) - \text{Received Voltage } (dB\mu V)$$

Shielding

Skin depth:

$$\delta = \frac{1}{\alpha} = \sqrt{\frac{2}{\mu\omega\sigma}}$$

Absorption loss:

$$A = 20\log\frac{E_o}{E_o e^{-\alpha z}} = 8.686\frac{z}{\delta}$$

Reflection loss:

$$R = 20\log\frac{|Z_W|}{4|Z_S|} = 20\log\left[30\pi\sqrt{\frac{\sigma}{\omega\mu}}\right] \text{dB}$$

Rectangular waveguide:

Cut-off frequency

$$f_{c,mn} = c\sqrt{\left(\frac{m}{2a}\right)^2 + \left(\frac{n}{2b}\right)^2}$$

Attenuation factor and phase factor

$$\gamma_{mn} = \sqrt{\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right] - k^2} = \alpha + j\beta$$

End of Paper.